PHOTOMETRIC AND SPECTROSCOPIC OBSERVATIONS OF TWO δ SCUTI VARIABLES: V919 HERCULIS AND V927 HERCULIS

by

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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

PHOTOMETRIC AND SPECTROSCOPIC OBSERVATIONS OF

TWO δ SCUTI VARIABLES:

V919 HERCULIS AND V927 HERCULIS

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Department of Physics and Astronomy

Senior Thesis

New photometric observations for V919 Her ($\alpha_{2000} = 16^h49^m31\overset{s}{.}98$, $\delta_{2000} = +26°02'05.53''$) and V927 Her ($\alpha_{2000} = 16^h56^m17\overset{s}{.}998$, $\delta_{2000} = +50°07'35.86''$). Six nights of photometric observations of V919 Her were obtained at the 0.4-m David Derrick Telescope (DDT) of the Orson Pratt Observatory (OPO), the 0.4-m telescope of the West Mountain Observatory (WMO), and the 1.8-m Plaskett telescope of the Dominion Astrophysical Observatory (DAO). Six nights of photometric observations of V927 Her were obtained at the 0.4-m DDT of the OPO, and the 1.8-m Plaskett telescope at DAO. Spectroscopic observations of both stars were made at the 1.2-m and 1.8-m telescopes at DAO. Rolland et al. (2006) recently quoted a period for V919 Her of 0.1037 days. Hintz & Garvin (2000) has published two closely spaced periods of 0.130512 days and 0.124981 days for V927 Her. With very little published about either star, the current data will extend the baseline of both stars, and will allow us to investigate their periods, frequencies, amplitudes, and radial velocities.

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I would like to thank Brigham Young University and Dominion Astrophysical Observatory for letting me use their telescopes. I would also like to thank Dr. Eric Hintz and Tabitha Bush for helping me with the reductions.

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Chapter 1

Introduction

Variable star research is a growing branch in astronomy. Brigham Young University (BYU) has been involved with variable star research for several years and has developed a strong undergraduate program in the field. With easy access to a 0.4-m Newtonian/Cassegrain telescope on campus and three research grade telescopes on West Mountain, BYU has become a national competitor in the hunt for and analysis of variable stars. BYU also has close ties to Dominion Astrophysical Observatory in Victoria, Canada which has a 1.2-m and 1.8-m telescope. With these resources, not to mention the expert direction of a nationally recognized faculty, I began researching two δ Scuti variables.

1.1 What Are Variable Stars?

Any star that changes its magnitude is considered to be a variable star. Supernovae are stars that blow up in one massive, super bright explosion and then quickly dim. This can be considered variable. Variable stars can be in binary systems with other stars or planets. For example, when a planet passes between the earth and its star, the star's brightness decreases; this is known as an eclipsing variable star. However, most variable stars are ones that have unstable atmospheres. The instability of the atmosphere allows gravity to pull the star's outer layers in towards the core until it becomes so dense that the pressure build up begins to push the atmosphere back outward. As the star expands, the inward force of gravity begins to overcome the outward force of pressure, and the star proceeds to collapse again. It becomes a seemingly never ending cycle that can be extremely consistent.

These variable stars can have periods of pulsation that last from minutes to years. In the interest of time, I have studied δ Scuti variables, which are short period variables that allow me to see full cycles of pulsation on the order of hours. δ Scuti is a name for a class of variable stars that are, for the most part, defined by having a period of one to four hours. Thus, it is often possible to see two or three full cycles in a given night of observing. With this information in mind, it is astounding to imagine a star, which can be up to several times as large as the Sun, expand and contract in a matter of two or three hours.

1.2 Why Study Variable Stars?

One reason to look for and study variable stars is to locate planets. Planet hunting has been booming with interest over the past few years and one popular method of searching for planets is what I described above. Astronomers look for eclipsing variable stars, those whose light is being blocked by a planet. Another reason for studying variable stars is to understand the internal structure of a star. Currently we do not have the technology to peer inside and below the surface of a star to analyze its interior; however, analyzing the large scale pulsation that gives rise to the tumultuous atmospheric conditions can provide insight into the inscrutable stellar interior. Complex computer models on stellar evolution and theory have been created in hopes of explaining how this interior is constructed. By studying variable stars we can compare their behavior with the computer model's to see if it is accurate. Studying the variability of stars can also give information about their metallicity content, distances, temperature, structure, and size.

1.3 Why V919 Her and V927 Her?

I chose to study V919 Her and V927 Her for several reasons. First, both stars have abnormal period fluctuations which makes studying them challenging, and understanding them even more so. V927 Her has actually shown signs of interesting period ratios which I will address later. From its peculiar behavior, it is even possible that V927 Her could fall under the γ Doradus class of variable stars. I suspect that these abnormal characteristics are part of the reason why these stars have not yet been extensively studied. Hence there is a great need for data in order to better understand their pulsations. Second, in a paper by Rolland et al. (2006) it was suggested that V919 Her has at least 15 different frequencies. If this is true it would make a great candidate for further astroseismology studies. Third, the logistics were favorable. The constellation Hercules was high in the night sky during my observation window. They are both δ Scuti variables which means that they have periods short enough to view several in one night. Their apparent magnitudes were perfect for the equipment which I used, and, finally, they had enough comparison stars in the CCD field of view such that I could use aperture photometry.

1.4 Previous Studies

1.4.1 V919 Her

V919 Her (BD+26 2906, HD 151938, HIP 82346, SAO 84625) is located at $\alpha_{2000} = 16^h 49^m 31\overset{s}{.}98$, $\delta_{2000} = +26°02'05.53''$. Rolland et al. (2006) recently quoted a period for V919 Her of 0.1037 days. This paper also suggests that there are at least 15 different frequencies that are associated with this star. Table 1.1 shows a breakdown of the 15 frequencies found. The variability Annex of the Hipparcos Catalogue (ESA 1997) reports V919 Her to have a spectral type of F2 and a ranging magnitude between 8.42 and 8.46.

	Freq. (c/d)	Period (d)	Amplitude
1	9.42657	0.10608	0.0533
2	9.64507	0.10368	0.0181
3	7.25937	0.13775	0.0068
4	12.83665	0.077902	0.0062
5	19.07163	0.05243	0.0056
6	12.70866	0.07869	0.0046
7	10.21542	0.09789	0.0039
8	9.99177	0.10008	0.0038
9	7.83283	0.12767	0.0030
10	14.60388	0.06848	0.0030
11	7.04325	0.00469	0.0029
12	17.81190	0.05614	0.0022
13	26.38560	0.03790	0.0021
14	2.59150	0.38588	0.0020
15	18.02880	0.05547	0.0016

Table 1.1: V919 Her frequencies found by Rolland et al. (2006)

1.4.2 V927 Her

V927 Her (BD+50 2346, HD 234366, HIP 82883, SAO 30162) is located at $\alpha_{2000} = 16^h56^m17^s.998$, $\delta_{2000} = +50°07'35.86''$. Hintz & Garvin (2000) has published two closely spaced periods of 0.130512 days and 0.124981 days for V927 Her. Duerbeck (1997) lists V927 Her (although it is identified as V925 Her) as an F5 V star and Hintz & Garvin (2000) found it to have an average magnitude of 9.92. Hintz & Garvin (2000) also makes an interesting observation about the classification of the star; they found only two reliable frequencies that yielded a period ratio of 0.96. A third frequency of 0.57 c/d was also found; however, more data is needed to confirm it. This third frequency is not equivalent to f2-f1 which means that V927 Her would be more characteristic of a γ Doradus type star. Table 1.2 shows a breakdown of the frequencies discovered by Hintz & Garvin (2000).

	Freq. (c/d)	Period (d)
1	7.6628	0.130512
2	8.0020	0.124981
3	0.57	1.75

Table 1.2: V927 Her frequencies found by Hintz & Garvin (2000)

Chapter 2

Procedure

2.1 Acquiring Data

2.1.1 Photometric Data

I acquired photometric data over 11 nights of observing for V919 Her. These observations were made between 26 May 2006 and 12 September 2006. Nine of these nights of observation were taken from the 0.4-m David Derrick Telescope (DDT) of the Orson Pratt Observatory (OPO), one night from the 0.4-m telescope of the West Mountain Observatory (WMO), and one night from the 1.8-m Plaskett telescope of the Dominion Astrophysical Observatory (DAO). Of these 11 nights, only six were photometric. Only the photometric nights were used in this analysis. Six nights of data were taken for V927 her, all of them from the DDT. These data were taken between 18 May 1999 and 01 July 1999, and between 14 July 2006 and 22 July 2006. Data taken from the OPO were obtained with an SBIG ST-1001 CCD mounted at the Cassegrain focus of the telescope. This gave a plate scale of 0.98 arcsec/pixel with a full field of view of 16.6'x16.6' (1kx1k). All observations taken from the OPO were made through a standard Johnson V filter modeled after Bessell (1990). Data taken from the WMO were obtained with an SBIG ST-1301 CCD mounted at the Cassegrain focus of the telescope. This gave a plate scale of 1.6 arcsec/pixel. All observations taken from the WMO were made through a standard Johnson V filter modeled after Bessell (1990). Data taken from the DAO were obtained with an E2V-1 CCD mounted at the Cassegrain focus of the telescope. This gave a plate scale of 0.60 arcsec/pixel. All observations taken from the DAO were made through a standard Johnson V filter modeled after Bessell (1990).

2.1.2 Spectroscopic Data

Three nights of spectroscopic observations had been previously done for V919 Her in June 2002. All of these observations were taken from the 1.2-m telescope at DAO. 11 nights of spectroscopic observations were acquired for V927 Her, three during February 2003, and eight during April 2004. All of these observations were taken from the 1.8-m Plaskett telescope at DAO. Observations obtained with the 1.8-m Plaskett telescope used the Cassegrain spectrograph and the 21121B grating. The grating is blazed at 4100 Å and yields 15 Å mm^{-1}. Using the Site2 CCD with 15 m pixels results in 0.23 Å $pixel^{-1}$. The grating was set to give a central wavelength of 4773 Å with coverage from 4570 to 4970 Å . Spectra taken from the 1.2-m telescope at DAO used the Coudé spectrograph using the 32121 grating. The grating is blazed at 5000 Å and yields 10.1 Å mm^{-1}. Using the Site4 CCD with 15 m pixels gives 0.15 Å $pixel^{-1}$. FeAr arcs were used for all of the wavelength calibrations.

Chapter 3

Reduction & Analysis

3.1 Photometric Data Reduction

I reduced all frames using standard IRAF methods. First, at twilight each night I took flat field frames (about 10 each night) that I could use for calibration. At the end of each night I took about 25 dark frames (with exposure lengths approximately resembling the object exposure lengths) and 25 bias (zero) frames. Next, I extracted all of the bias, dark, flat, and object frames. I then averaged all of the bias frames and combined them into one master bias frame. Following that, I averaged all of the dark frames, subtracted the noise from the master bias frame, and combined them into one master dark frame. Then I averaged all of the flat frames, subtracted the noise from the master dark frame, and combined them into one master flat frame. Finally, I subtracted the noise from the master flat frame from each individual object frame, making them fit for analysis, after which I used the methods detailed in Hintz et al. (1997) to select a set of comparison stars for the two variables that I am studying. From that list I looked at the relative errors of each star (fluctuations in their magnitudes) to find the most stable comparison stars or the ones whose magnitudes varied the least. Once I identified two or three stable comparison stars, IRAF was then able to compare the fluctuations of the variable stars to the stable ones. The light curves were then generated from these data.

The star fields from the Digitized Sky Survey of V919 Her and V927 Her are shown in Figure 3.1 and Figure 3.2 respectively. The numbered stars were the most stable stars and were thus used for the comparison stars. Using aperture (differential) photometry, I developed light curves for each night of observations for both stars. The collected data of apparent magnitudes and their associated times were then plugged into the software program Period04. This program analyzed the data from each night of observations and determined the most likely periods.

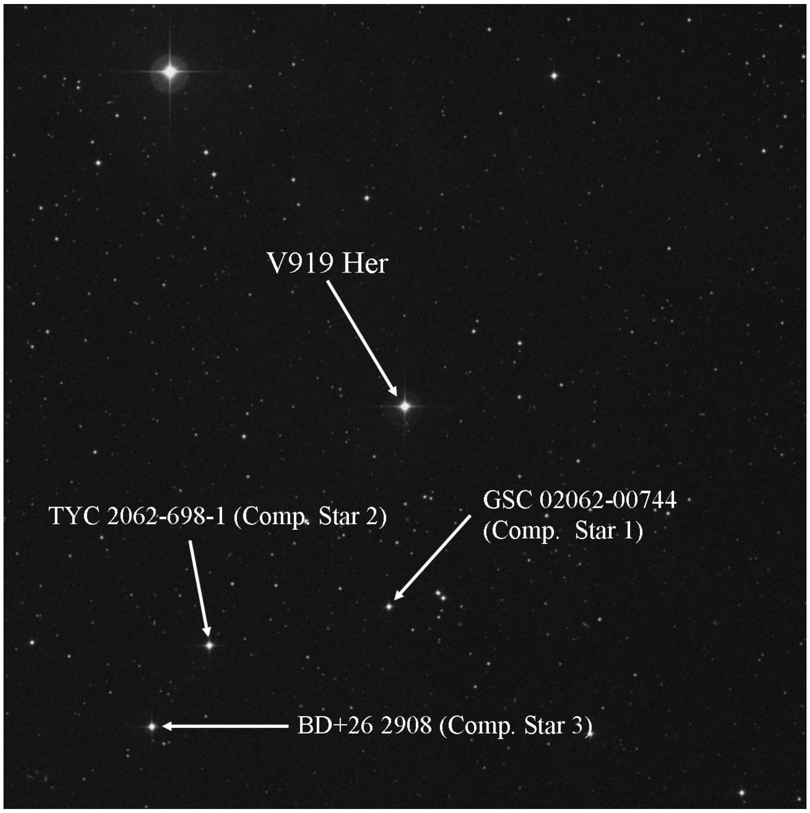

Figure 3.1: This is the star field of V919 Her, taken from the Digitized Sky Survey. The comparison stars are numbered.

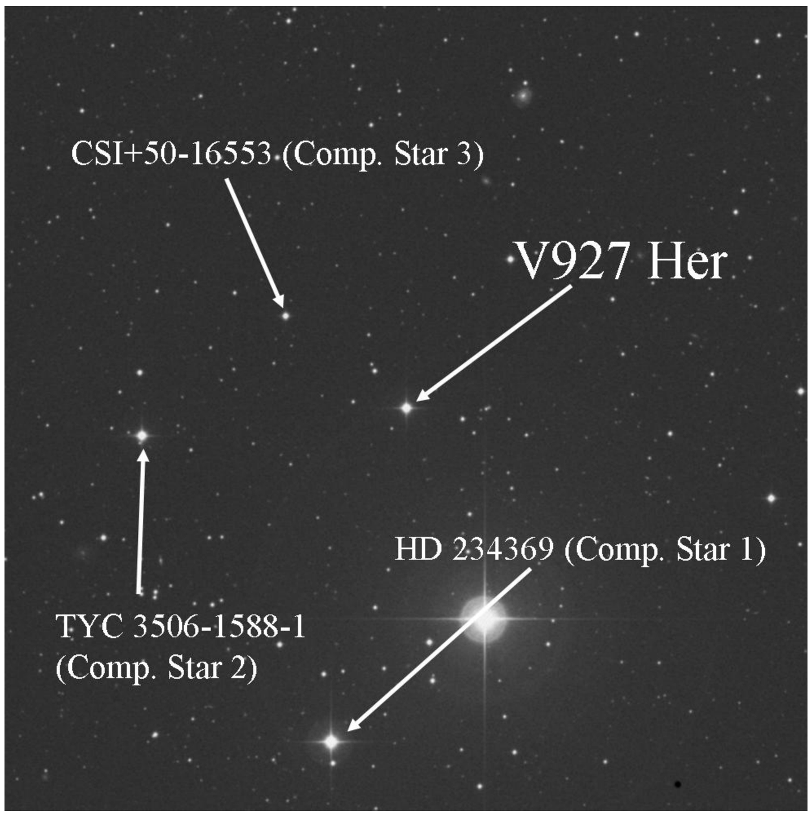

Figure 3.2: This is the star field of V927 Her, taken from the Digitized Sky Survey. The comparison stars are numbered.

3.2 Spectroscopic Data Reduction

The spectra were reduced again using standard IRAF reductions. Zeroes, flats, and arcs (FeAr) were taken and applied for calibration purposes. For analysis, the DoSlit command was used to transfer the spectra from 2-D to 1-D. Also, the RVIDLINES command was used to determine the radial velocities of the two stars.

3.3 Photometric Analysis

3.3.1 V919 Her

Analyzing V919 Her has proven to be a challenge. It is evident, just from looking at light curves, that V919 Her has no simple period solution. Figures 3.3 through 3.8 show quite clearly how various frequencies are regularly interfering, either constructively or nonconstructively. Each figure is formatted to have an amplitude range of 0.2 (y-axis) and a time domain of 0.3 days (x-axis). Figure 3.3 shows the one night of data taken from WMO. I took 1400 frames which created a very solid light curve. Figure 3.4 shows a very clean rise in magnitude up to a maximum and then a dip down to a minimum. It is interesting to note that the rise up to the maximum light comes from a deeper minimum than the one following the maximum, thus showing evidence of beat frequencies. All three comparison stars were used to create this light curve. Figure 3.5 is similar to the previous one except that it goes from a shallow minimum to a deeper minimum. This curve is particularly interesting because of the small hiccup that is visible in the rise to the maximum. This hiccup is a definite sign of a smaller beat frequency. All three comparison stars were used to create this light curve. Figure 3.6 is the most telling. It clearly shows a smaller beat frequency inside the primary frequency. Only comparison stars 2 and 3 were used to create this light curve. Figure 3.7 is similar to the first two. Again, all three comparison stars were used to create this light curve. Figure 3.8 shows data from a shorter night of observing, but it still adds to the total period solution. Only, comparison stars 2 and 3 were used to create this light curve.

There were a several nights of observations that did not produce good data. For example, Figure 3.9 is a light curve of the data taken at the DAO with the 1.8-m Plaskett telescope. The conditions started out good, but thin clouds started to move in quite rapidly, distorting the data. Figure 3.10 shows data taken from the OPO with the 0.4-m DDT. These observations did not last long enough to be worthwhile, and again the data was distorted by poor seeing conditions.

After I plugged the data from this study into Period04, I determined a primary period of 0.08959 days with approximately six beat frequencies. This primary period and the number of frequencies found vary from the information recently quoted in Rolland et al. (2006). Two phase diagrams produced by Period04 show quite vividly how our primary periods disagree. They can be seen in Figures 3.11 and 3.12. Figure 3.11 is the phase diagram associated with the period quoted in Rolland et al. (2006), and Figure 3.12 is the phase diagram showing the best period found in this study.

Table 3.1 shows a breakdown of the seven most prominent frequencies of V919 Her with 1 being the primary frequency and 2 through 7 being beat frequencies. This conclusion does not necessarily mean that my data are correct and Rolland et al. (2006) is wrong, but it does show that there is a discrepancy that must be further analyzed in order to know the exact period as well as how many real beat frequencies actually exist.

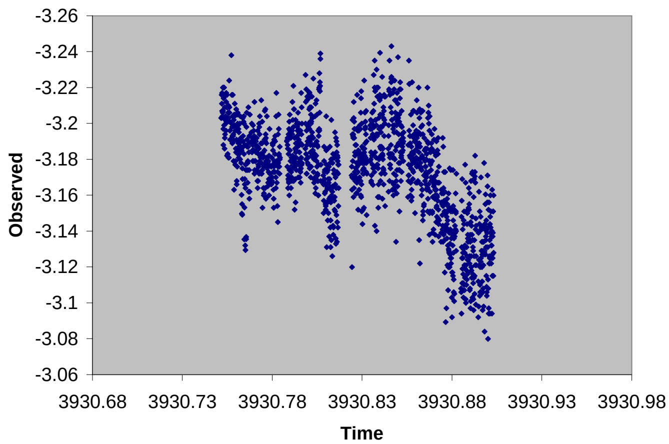

Figure 3.3: V919 Her light curve for 14 July 2006, data taken at the WMO.

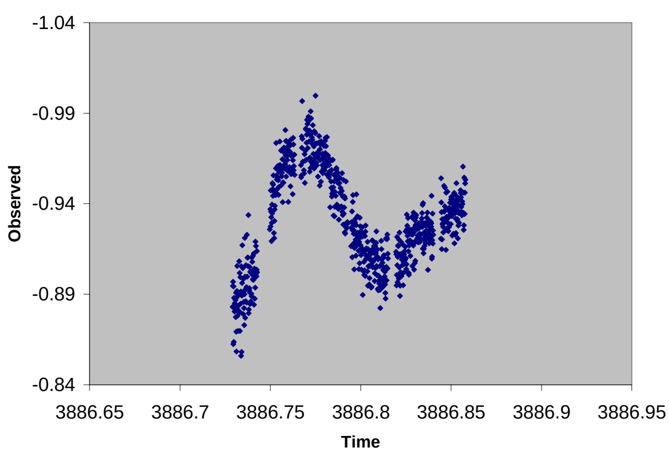

Figure 3.4: V919 Her light curve for 31 May 2006, data taken at the OPO. An aperture radius of 6 pixels was used.

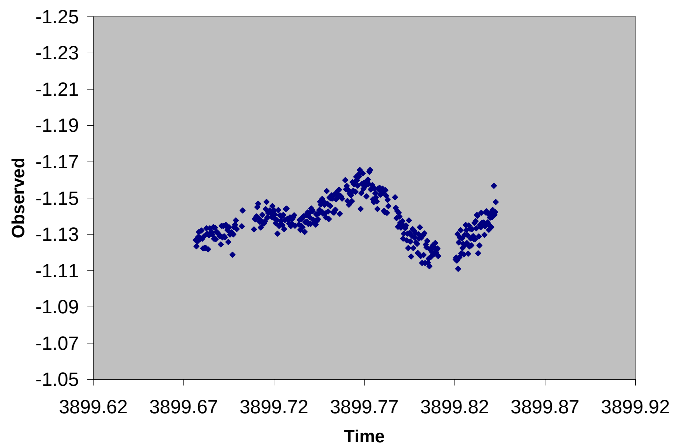

Figure 3.5: V919 Her light curve for 13 June 2006, data taken at the OPO. An aperture radius of 10 pixels was used.

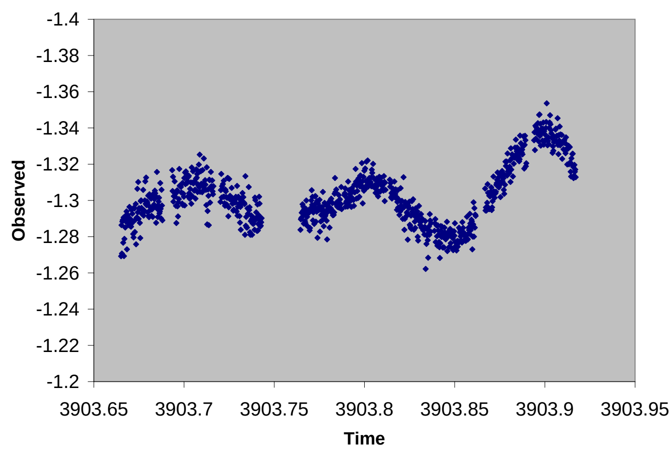

Figure 3.6: V919 Her light curve for 17 June 2006, data taken at the OPO. An aperture radius of 7 pixels was used.

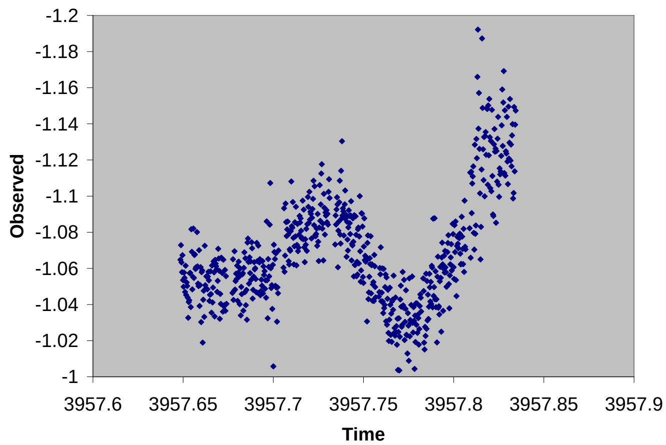

Figure 3.7: V919 Her light curve for 10 August 2006, data taken at the OPO.

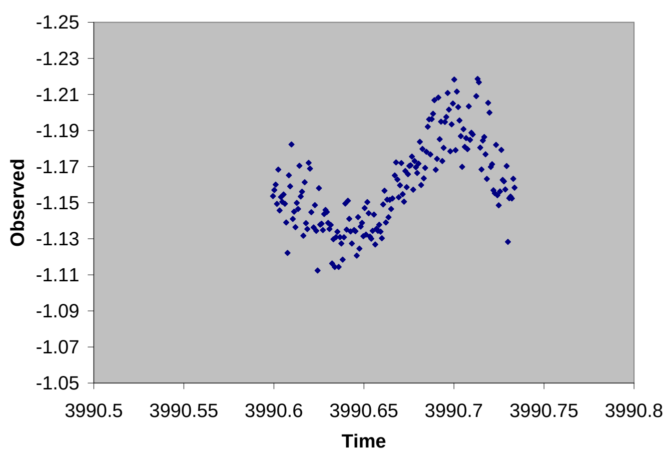

Figure 3.8: V919 Her light curve for 12 September 2006, data taken at the OPO. An aperture radius of 3 pixels was used.

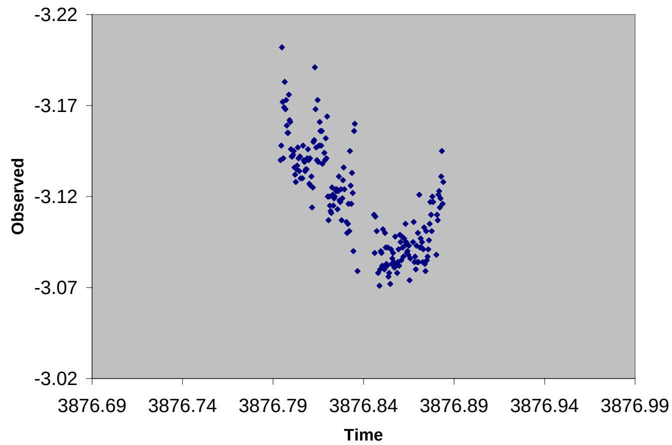

Figure 3.9: V919 Her light curve for 21 May 2006, data taken at the DAO. Creeping cloud cover distorted the data.

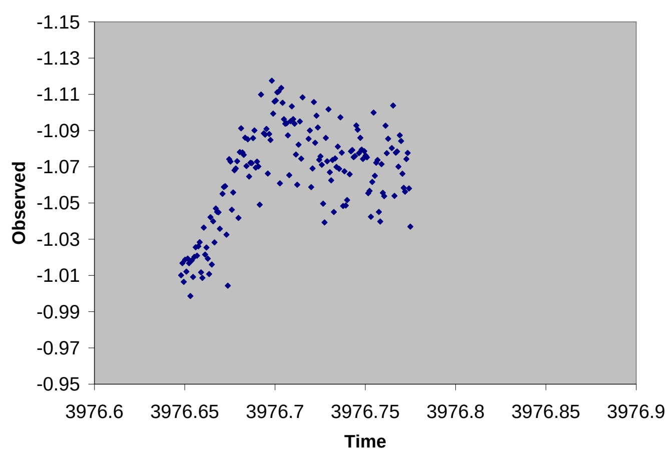

Figure 3.10: V919 Her light curve for 29 August 2006, data taken at the OPO. Poor seeing conditions distorted the small amount of data taken.

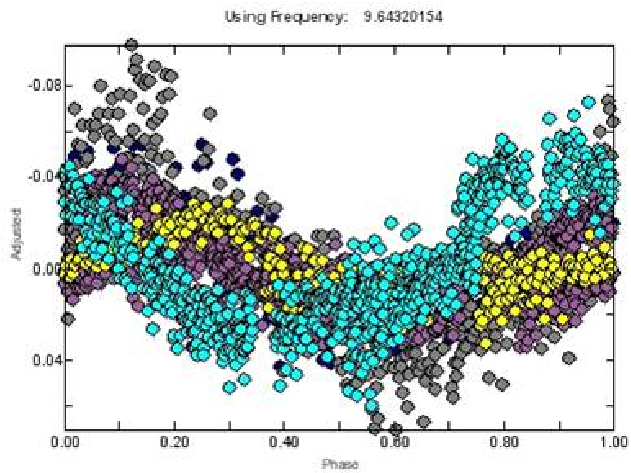

Figure 3.11: V919 Her phase diagram showing how my data phases with the period quoted in Rolland et al. (2006).

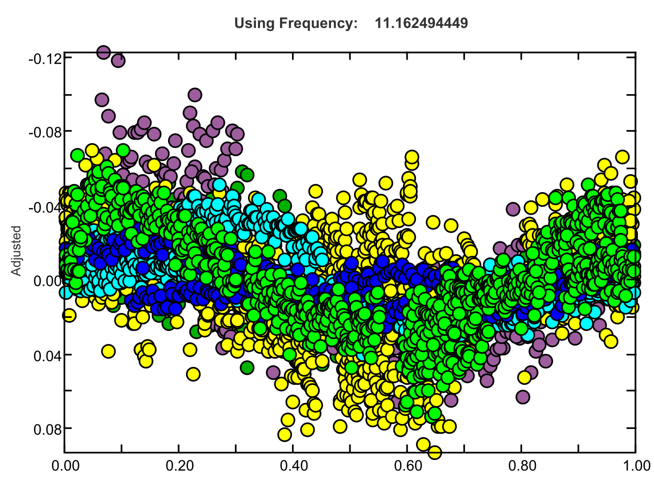

Figure 3.12: V919 Her phase diagram showing my data phased with the period of best fit.

	Freq. (c/d)	Period (d)	Amplitude
1	11.16249	0.08959	0.02373
2	7.17709	0.13933	0.02974
3	14.35370	0.06967	0.01173
4	10.96250	0.09122	0.02117
5	3.09938	0.32265	0.01345
6	3.48927	0.28659	0.02966
7	25.33928	0.03946	0.00066

Table 3.1: V919 Her Period Solution.

3.3.2 V927 Her

Analyzing the V927 Her data with Period04 I found its period to be 0.13042 days. This is fairly consistent with Hintz & Garvin (2000) who found two closely spaced periods of 0.130512 days and 0.124981 days; however, I did not find the second period previously reported. Figures 3.13 through 3.18 are light curves from all six nights. Each light curve is set to an amplitude range of 0.4 (y-axis) and a time domain of 0.3 days (x-axis). The data taken in 2006 used all of the comparison stars shown in Figure 3.2, but the comparison stars used for the 1999 data vary quite a bit. This explains, at least partially, why the amplitude values are so different between each light curve. These light curves are very clean and noise free compared to V919 Her; however, the frequencies in this star are as strange as those in V919 Her. These curves do not visibly show the beat frequencies as well, but Period04 was able to identify them. Figure 3.19 is the phase diagram for V927 Her, showing the best period found in this study.

In Table 3.2 we can see a break down of the periods and frequencies that are in the data set. Again, the primary period is 1, with 2 through 7 being beat frequencies. Particularly interesting is the summation of frequencies 2 and 4. Together they are almost exactly frequency 1, which would show where frequency 1 comes from. There are other interesting summations also possible in this table. Once again a larger data set would be helpful to determine a more complete period solution.

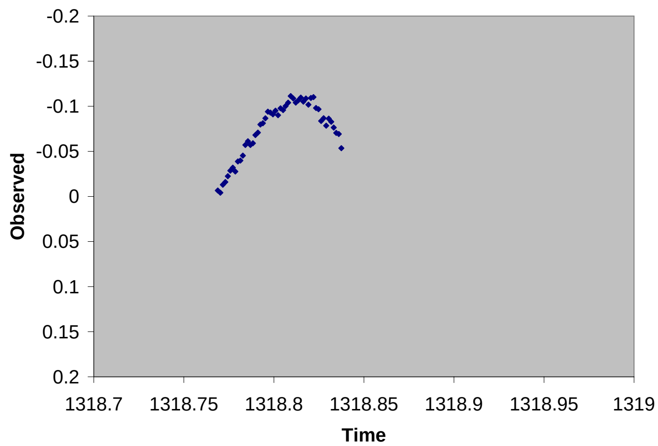

Figure 3.13: V927 Her light curve for 20 May 1999. An aperture radius of 5 pixels was used.

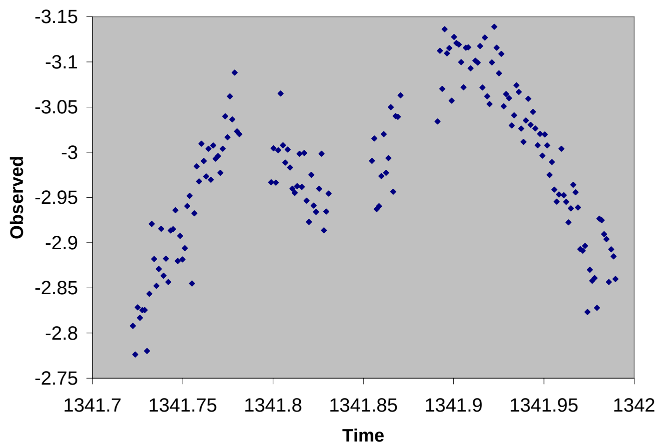

Figure 3.14: V927 Her light curve for 12 June 1999. An aperture radius of 7 pixels was used.

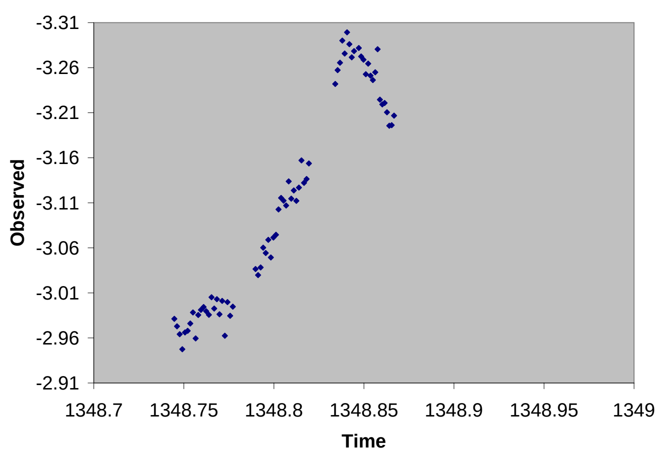

Figure 3.15: V927 Her light curve for 19 June 1999. An aperture radius of 3.8 pixels was used.

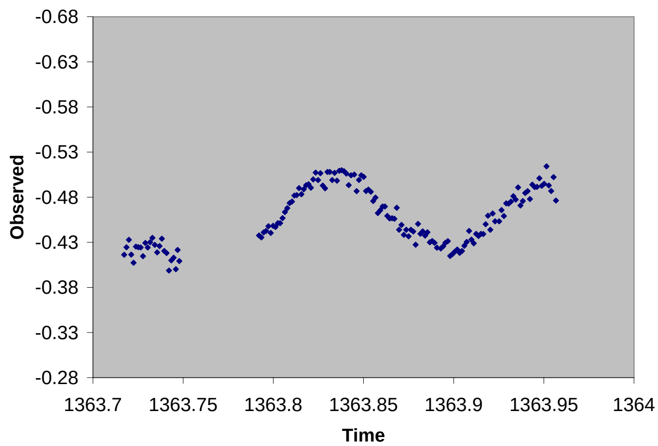

Figure 3.16: V927 Her light curve for 01 July 1999. An aperture radius of 3.8 pixels was used.

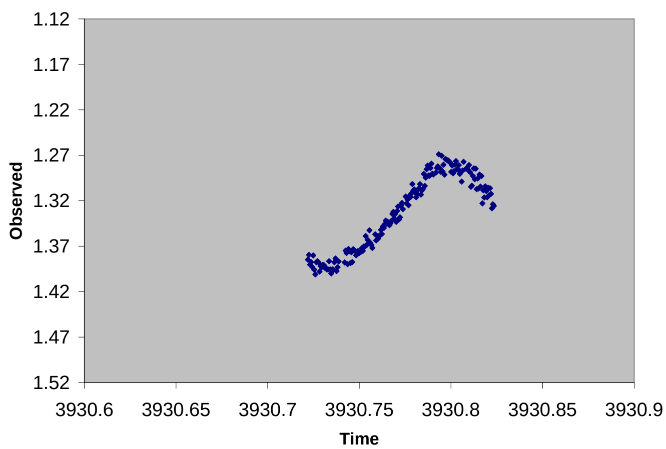

Figure 3.17: V927 Her light curve for 14 July 2006. An aperture radius of 3 pixels was used.

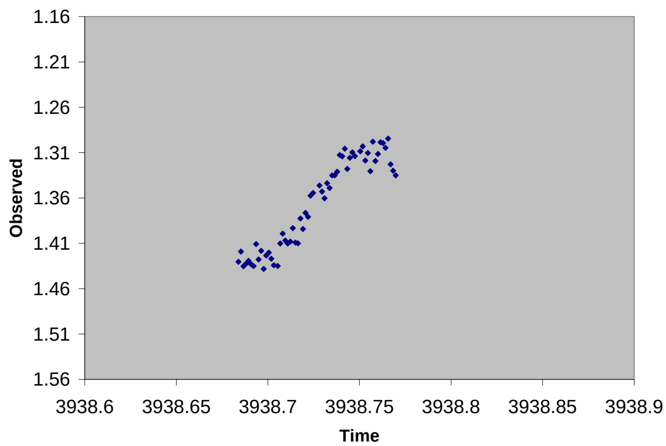

Figure 3.18: V927 Her light curve for 22 July 2006. An aperture radius of 3 pixels was used.

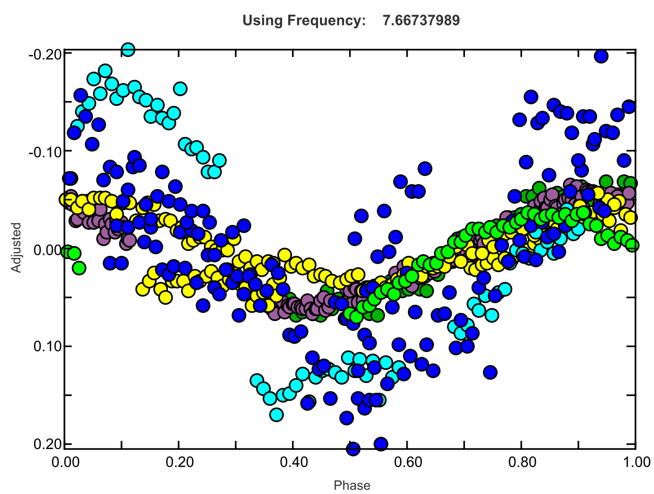

Figure 3.19: V927 Her phase diagram showing my data phased with the period of best fit.

	Freq. (c/d)	Period (d)	Amplitude
1	7.66738	0.13042	0.06466
2	3.72328	0.26858	0.04163
3	4.60967	0.21694	0.03344
4	3.97441	0.25161	0.02900
5	9.31713	0.10733	0.02148
6	16.2439	0.06156	0.00772
7	12.01244	0.08325	0.00964

Table 3.2: V927 Her Period Solution.

3.4 Spectroscopic Analysis

3.4.1 V919 Her

From spectra we can learn many things, from how big and hot a star is to which direction in space it is traveling. Figure 3.20 is an example of a spectra that was taken for V919 Her. V919 Her was found to be a spectral type of F2 IV and has an average radial velocity of 2.83 km/sec. The measured radial velocities are given in Table 3.3. Figure 3.21 shows the V919 Her phase plot along side a phased radial velocity plot. By comparing the two plots, I can analyze the location of the radial velocity points to help rule out the possibility of V919 Her being an eclipsing variable. The two equal radial velocity points are near the same location as the minimum on the phase plot, which is expected for a standard variable star. This helps rule out any possibilities of V919 Her being an eclipsing variable.

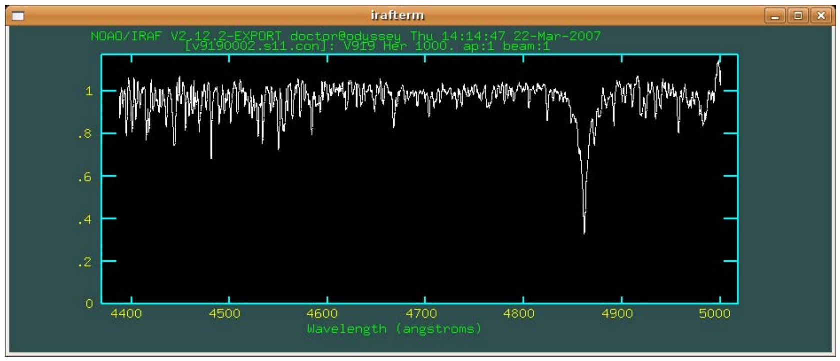

Figure 3.20: Spectra of V919 Her.

	HJD	V919 Her RV (km s^{-1})	Instrument
1	2452433.7654	3.5 ±0.7	Spec.
2	2452433.7779	2.5 ±0.8	Spec.
3	2452433.7903	2.5 ±0.9	Spec.

Table 3.3: Radial Velocity Measurements for V919 Her.

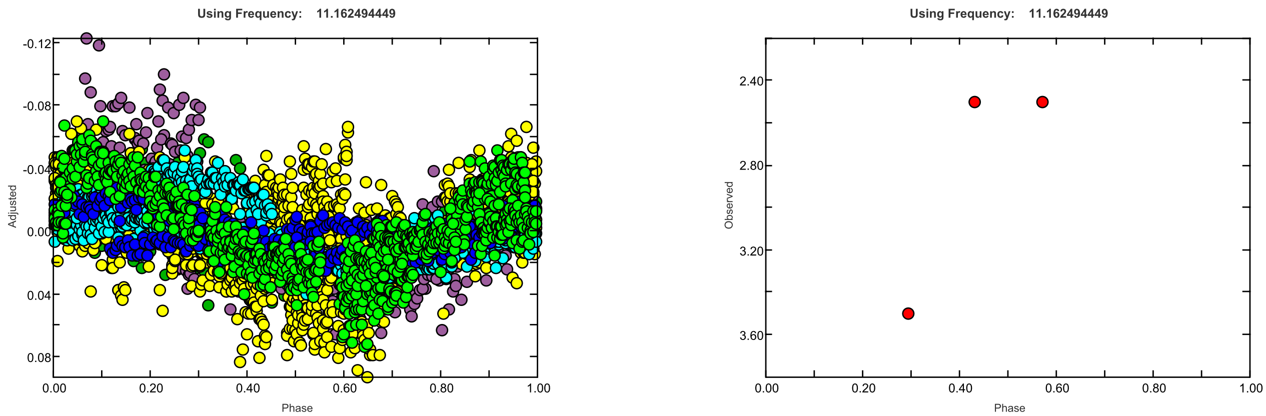

Figure 3.21: V919 Her phase plot and phased radial velocity plot.

3.4.2 V927 Her

An example spectra for V927 Her is shown in Figure 3.22. V927 Her was found to be a spectral type of F3 IV and has an average radial velocity of -7.63 km/sec. The measured radial velocities are given in Table 3.4. An F star is one that is about one and a half times larger than our sun and a few thousand degrees hotter. In the future I also hope to determine rotational velocities and metal contents for these two stars. Figure 3.23 shows the V927 Her phase plot along side a phased radial velocity plot. The three sloping radial velocity points are increasing rapidly just as the light curve dives into its minimum. This again is expected for a standard variable star. This helps rule out any possibilities of V927 Her being an eclipsing variable.

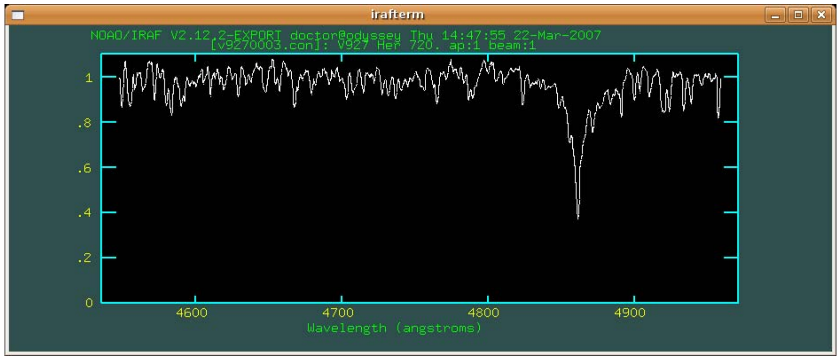

Figure 3.22: Spectra of V927 Her.

	HJD	V927 Her RV (km s^{-1})	Instrument
1	2452693.0462	-8.8 ±0.8	Spec.
2	2452693.0547	-7.5 ±1.0	Spec.
3	2452693.0632	-6.6 ±1.1	Spec.

Table 3.4: Radial Velocity Measurements for V927 Her.

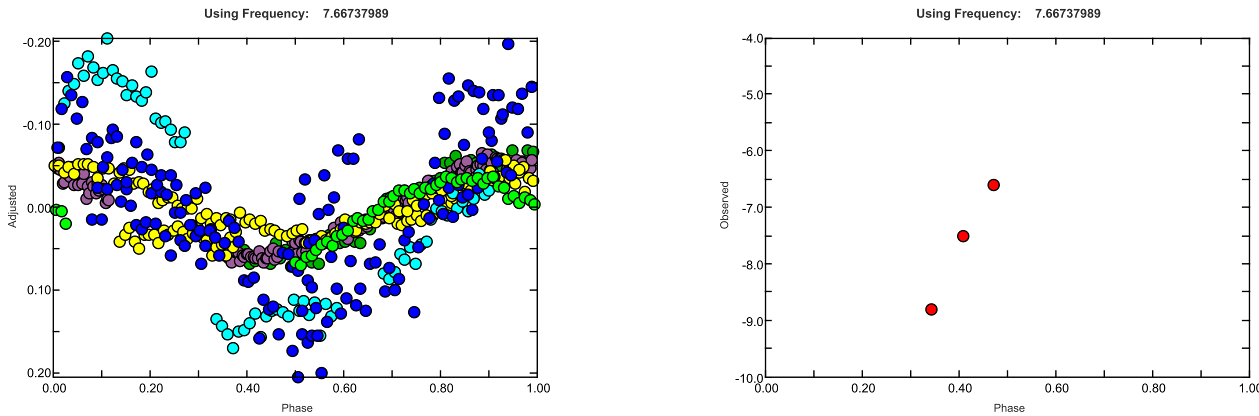

Figure 3.23: V927 Her phase plot and phased radial velocity plot.

Chapter 4

Conclusions

4.1 Summary of Results

V919 Her and V927 Her have proven difficult to analyze. Rolland et al. (2006) has suggested over 15 frequencies associated with V919 Her, but only seven that are reasonable have been found in this study. Rolland et al. (2006) quotes the primary period for V919 Her to be 0.1037 days; however, when the data from this study were phased, a period of 0.08959 days emerged. The first period mentioned is the equivalent of 2h and 29m. The second period mentioned is the equivalent of 2h and 09m. So there is about a 20 minute discrepancy between the two. This is not a huge difference, but it is definitely noticeable.

Hintz & Garvin (2000) published two closely spaced periods of 0.130512 days and 0.124981 days for V927 Her. This study found the primary period of V927 Her to be 0.13042 days, which is within 10s of the first period mentioned by Hintz & Garvin (2000). The other frequencies found, however, do not match up with the second period suggested in Hintz & Garvin (2000). I was also unable to confirm the third period found by Hintz & Garvin (2000). The possibility of V927 Her being a γ Doradus variable simply was not confirmed by my data. All my data point V927 Her to being a complicated δ Scuti variable star.

4.2 Possibilities for Further Research

The study of these two stars is not complete. For V919 Her there is a discrepancy with the number of frequencies actually present. There is also a 20 minute discrepancy of the primary period found for the star. V927 Her seems to have a consistent primary period, but again there is a discrepancy with its more subtle frequencies. Fortunately, these problems can be dealt with. More photometric observations of both stars must be attained before complete period solutions for either star can be confirmed.

4.3 Recommendations

I will be graduating in April 2007 and, therefore, will be unable to follow this project through to completion. I recommend that whoever endeavors to complete this project takes a minimum of seven nights of new photometric observations. Hopefully, with another seven full nights of data, the actual periods, frequencies, and other characteristics will be able to be published with confidence.

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