Lab 5
Spectroscopy
ASTR 329

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1 Objective

To investigate and plot the radial velocity curve for Beta Cephei using spectroscopy.

2 Introduction

The variable star Beta Cephei can be observed to have a periodic change in luminosity and an observable Doppler shift. The observed Doppler shift of the Helium absorbtion line via spectroscopic analysis can be used to derive the apparent radial velocity of the star. The changes in brightness are caused by the expansion and contraction of gases on the star's surface. When the star radiates upon Helium it expands and appears dimmer due to the higher opacity of Helium in it's higher ionization states comparted to lower ones. The gas then cools as it expands, becoming less opaque to the stars radiation which increases the stars apparent luminosity. This is a cyclical process with a very consistent period. The He I line occurs at 6678Å. Arc spectroscopy is used to calibrate this wavelength using a Thorium source heated in Argo gas. This will radiate onto the CCD creating a Th-Ar arc which can be used to calibrate the wavelength of the source spectrum.

3 Procedure

3.1 Data Reduction

The data was first reduced by modifying a IRAF script written by Dr. S. Yang. This is a general use script so it must be modified to work with the Beta Cephei data we are working with. The script automates the following actions.

Bias frames are combined and the floating bias is removed. Cosmic ray spikes are filtered out as well.

Flat frames are combined and the floating bias is removed. Again cosmic ray spikes are filtered out.

Th-Ar arc files are averaged coresponding to the data set.

Stellar frames are corrected for floating bias, bias, and dark frames.

$flat1d$ is used to do flat field corrections. Each row on the CCD is treated as a spectrum which removes the problem of getting near saturated rows in the flat fielded spectra caused by the division of small numbers.

spectra are extracted from 2D to 1D using a upper and lower bound of 25 for standard deviation rejection.

3.2 Data Processing

Once the reduction script had completed the following steps were followed:

The IRAF function *continuum* was used to fit a continuum to each spectra which the spectra were then normaled with.

The $identify$ function was then used on one file using the line list from linelists$that.dat in epar.

$reidentify$ was then run using the previously identified arc as a reference for all other arcs.

$refspec$ was then run for individual stellar spectra corresponding to their appropriate arc spectra wavelength references.

dispcor was then run to interpolate and select the individual spectral region where the He I line resides.

$fxcor$ was then used to get the relative radial velocities among the spectra.

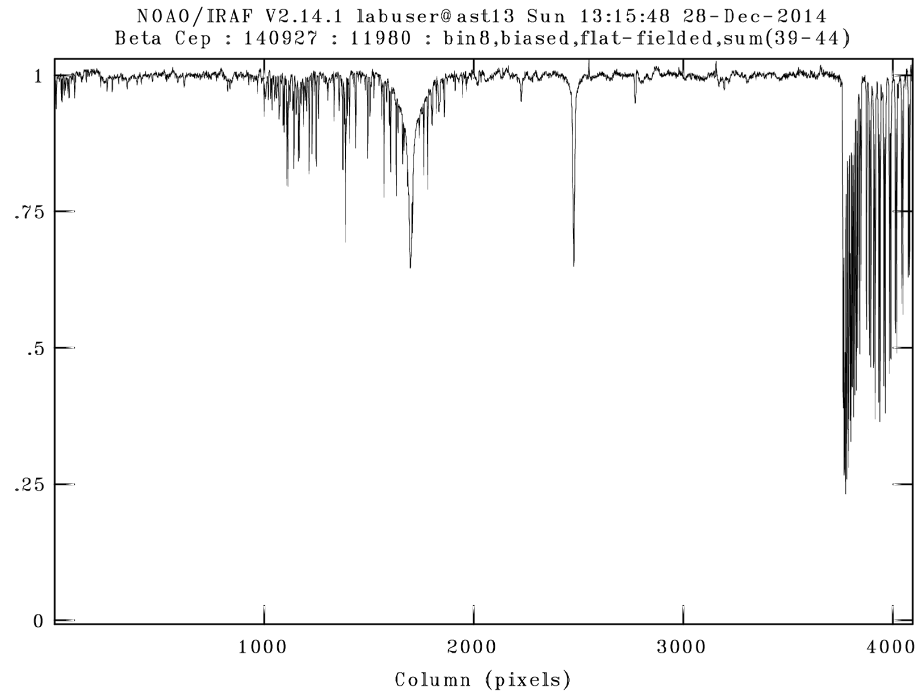

Figure 1: Continuum

3.3 Analysis

3.3.1 Continuum Fitting

Once reduce15.cl had completed running the reduced data was normalized with a continuum fit. The *continuum* command in IRAF transformed the raw reduced spectra into a level absorption spectra. This normalization by the continuum fit ensures that the same parameters are used to fit every image. We can do this because of the assumed similarity of all our images.

3.3.2 Identification of Features

Next the *identify* function was applied to one of Th-Ar arc files that was produced in the reduction process resulting in the above wavelength dependant spectra with identified lines.

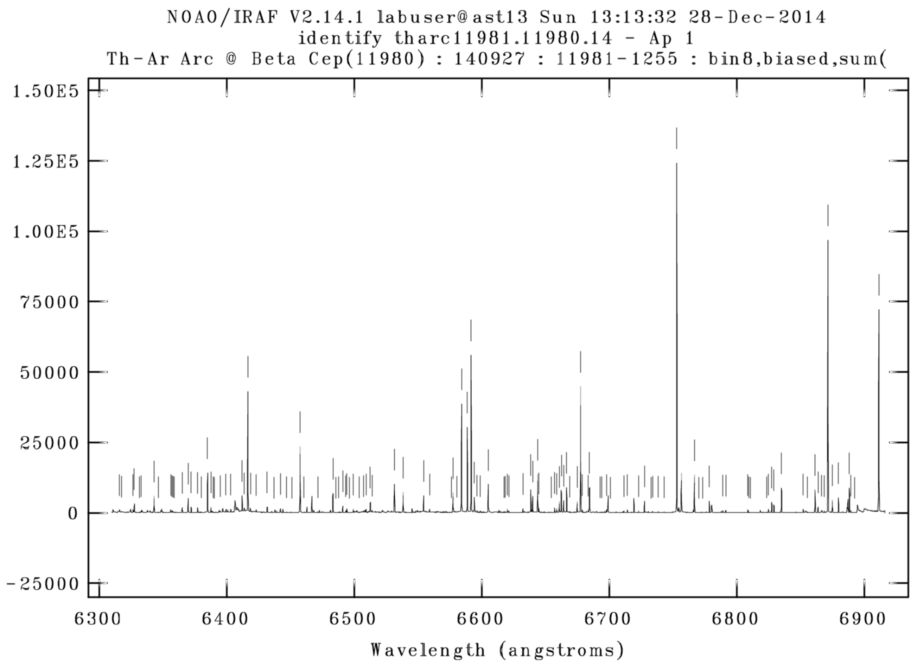

Figure 2: Spectra correlated with wavelength

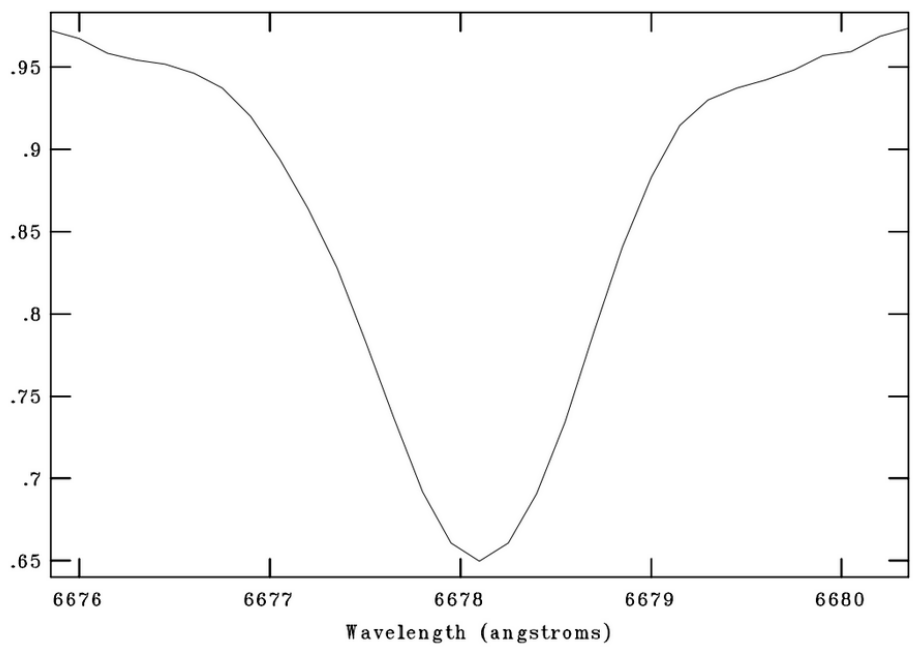

Figure 3: He I Absorbtion Line

3.3.3 The He I Absorbtion Line

3.3.4 Relative Radial Velocity Curve

Julian Date	FWHM	Rel Vel. (km/s)	Obs Vel. (km/s)	Hel Vel. (km/s)	Error (km/s)
546927.6687	108.6800	3.4730	-1.4780	3.4720	0.9370
546927.6720	108.7300	0.4870	-4.4630	0.4850	0.8780
546927.7225	107.7700	-20.3130	-25.2630	-29.3540	0.9080
546927.7615	105.8500	-9.5090	-14.4590	-9.5800	0.6600
546927.7872	104.4600	4.7910	-0.1600	4.7000	0.6420
546927.8037	105.4800	12.5110	7.5600	12.4070	0.9790
546927.8333	107.3100	14.3030	9.3520	14.1790	1.0460
546927.8486	105.6100	7.1690	2.2190	7.0360	1.1470
546927.8784	107.7400	-8.4880	-13.4390	-8.6380	1.0380
546927.9151	106.8500	-20.9490	-25.8990	-21.1140	0.6480
546927.9470	104.6300	-11.5320	-16.4830	-11.7080	1.2410
546927.9693	104.9000	-0.1310	-5.0810	-0.3110	1.1980
546927.9968	105.9300	13.5840	8.6340	13.4030	1.0710
546928.0227	106.9800	14.6880	9.7380	14.5060	0.9880
546928.0581	107.1500	-2.9650	-7.9150	-3.1420	1.0430

Table 1. Data aquired using *dispcor*. The velocities all clearly vary with time as we would expect for Beta Cephei.

3.3.5 Telluric Lines

Julian Date	FWHM	Rel Vel. (km/s)	Obs Vel. (km/s)	Hel Vel. (km/s)	Error (km/s)
2456927.67	28.61	0.45	-4.5	0.45	0.19
2456927.67	28.8	0.51	-4.44	0.51	0.16
2456927.72	29.5	0.06	-4.89	0.02	0.07
2456927.76	29.09	0.06	-4.89	-0.01	0.03
2456927.79	29.72	0.36	-4.59	0.27	0.12
2456927.8	29.52	-0.03	-4.98	-0.13	0.07
2456927.83	29.5	0.1	-4.85	-0.02	0.18
2456927.85	29.42	0.07	-4.88	-0.06	0.04
2456927.88	29.42	-0.09	-5.04	-0.24	0.33
2456927.92	29.32	-0.36	-5.31	-0.53	0.13
2456927.95	29.06	-0.09	-5.04	-0.27	0.15
2456927.97	29.31	-0.28	-5.23	-12.94	0.11
2456928.00	29.72	-0.18	-5.13	-0.37	0.08
2456928.02	29.87	-0.23	-5.18	-0.42	0.08

Table 2. Telluric O_2 line data. The Telluric lines originate from the earth's atmosphere and thus they can be used to correct for systematic wavelength errors in the He I lines because they are independent of each other. The average over all the telluric spectra produced in *dispcor* was used as the reference in $fxcor$.

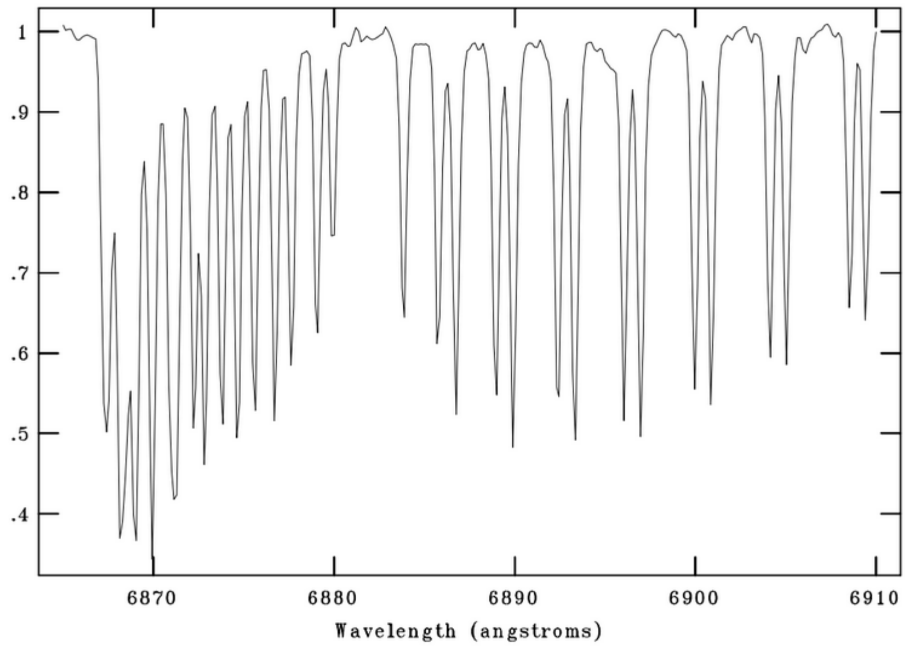

Figure 4: The Telluric Lines.

3.3.6 Telluric Subtraction

The values for the Telluric relative radial velocities were subtracted from the Hel values and the results were plotted as a function of the Julian Date to obtain the radial velocity curve (Figure 5.)

3.3.7 Curve Analysis

After fitting a sin wave curve to this data using the software "Graphical Analysis" we obtain Figure 6 and the following results.

Period $= \frac{2\pi}{33.02} = (0.190 \pm 0.00178)$ Days
Amplitude $= (19.64 \pm 0.924)$km/s
Phase = 0.300 Days

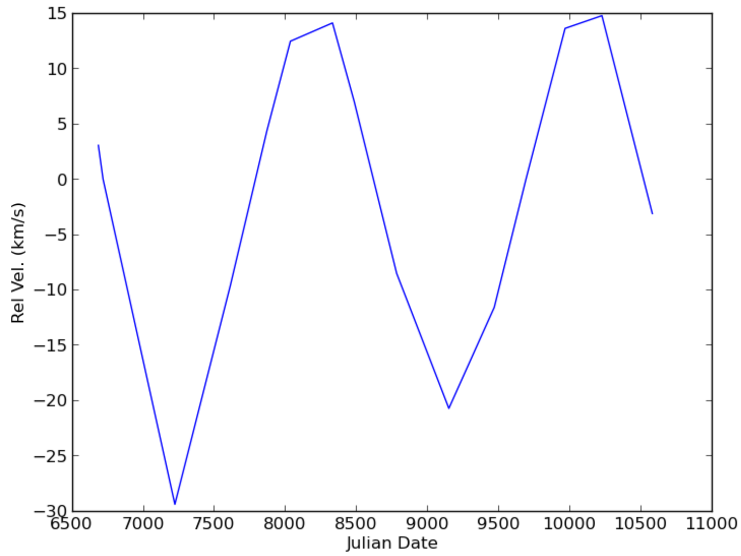

Figure 5: Radial Velocity Curve

4 Conclusions

A precise radial velocity curve was produced from analyzing the He I 6678Åline of Beta Cephei. The dominant source of error was determined to be from the opacity changes on the surface of due to the variable opacity of Helium when it is at different ionization levels. These radial velocity curves may be used to derive a number of exciting things such as the orbital period and perhaps whether or not very large planets orbit the star.

The derive curve yielded a Period of (0.190 ± 0.00178) Days with an Amplitude of (19.64 ± 0.924)km/s. This is consistent with the accepted value for the Period of 0.1904844 Days[1]

5 References

1. Beta Cephei. (2014, December 23). In Wikipedia, The Free Encyclopedia. Retrieved 08:10, January 2, 2015, from http://en.wikipedia.org/w/index.php?title=Beta_Cephei

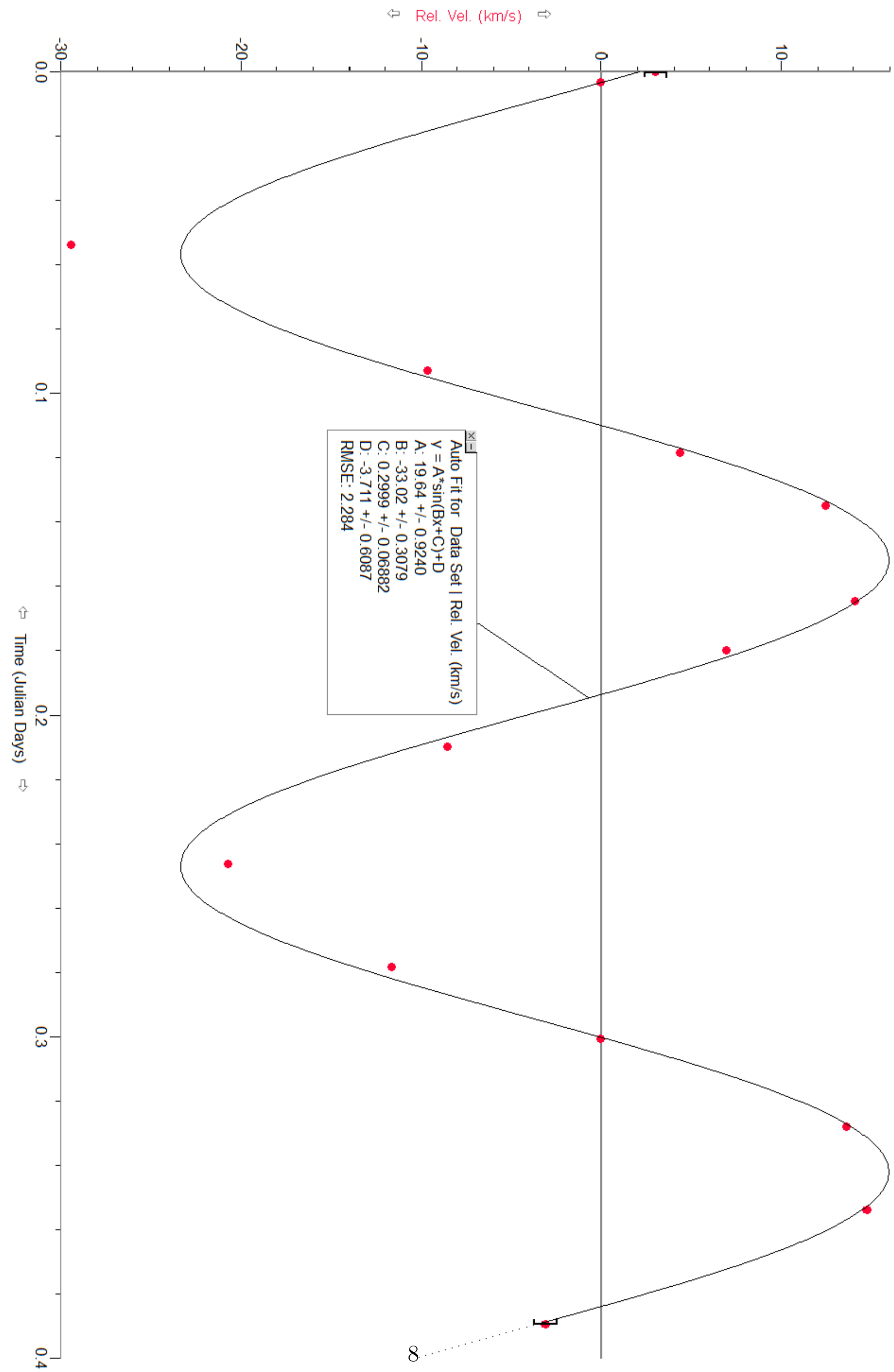

Figure 6: Radial Velocity Curve Fit